PhD thesis Proposal

Fracture of porous ceramics: application to the mechanical reliability of Solid Oxide Cells during thermal cycling

1. Context and issues

Solid Oxide Fuel Cells (SOFC) and Solid Oxide Electrolysis Cells (SOEC) are promising electrochemical converters operating at high temperatures. Among several advantages, SOFCs and SOECs can reach a very high efficiency without the use of specific electro-catalyst. Thanks to their reversibility, the same device can be alternatively used in fuel cell and steam electrolysis modes. The SOFC/SOEC are made of ceramic materials and they consist in two porous electrodes separated by a dense electrolyte. In planar configuration, the cells are assembled with metallic interconnects to form a stack of high power density. Because of the mismatch in Thermal Expansion Coefficients (TEC) between all the stack components, the cell layers are subjected to significant internal stresses. During the accumulation of start and shutdown of the system, the thermomechanical loading can induce damage in the electrode which leads to decrease the global system efficiency. Nowadays, the SOFC/SOEC mechanical degradation remains an issue for the application that still needs to be precisely investigated. In this frame, it is necessary to study the brittle fracture behavior of the porous SOFC/SOEC ceramics.

2. Work plan

2.1. Identification and validation of a local fracture criterion. The fracture properties of the SOFC/SOEC porous electrodes will be measured by using an available instrumented micro-indentation setup. For the experiments, specific micropillars will be prepared in the ceramic membranes with a Plasma Focused Ion Beam (PFIB). The uni-axial compression test will be conducted beyond the damage initiation in the material and the density of micro-cracks in the samples will be characterized by 3D tomography techniques. The micro-indentation tests will be then modelled by Finite Element Analysis (FEA). For this purpose, a three dimensional elastic model will be applied on the 3D electrode reconstructions. Accurate boundary conditions and loading will be applied on the 3D mesh to be representative of the micro-compression test. In order to help the identification of the boundary conditions, a simplified continuous modelling of the test will be conducted. Local criteria will be then applied on the 3D structure to predict the density of micro-cracks after test. The comparison with the experimental estimation of micro-cracks distribution should allow to identify the most appropriate fracture criterion for the porous ceramic.

2.2 Application to the SOEC technology: electrode damage during thermal cycle. A multi-scale approach is proposed to compute the local stresses in the electrode microstructure. Firstly, a macroscopic continuous model describing a typical geometry of a Single Repeat Unit (SRU) will be built with boundary conditions representative of the whole stack assembly. This macroscopic model will be used to determine the relevant boundary conditions that will be applied on the 3D electrode reconstruction. At this microscopic scale, the computation will provide the local stress fields in the solid network of the porous electrodes. These methodology will be applied for different scenarios of starts and shutdowns of the system (i.e. number of thermal cycles). By using the validated local fracture criterion, the density and the repartition of micro-cracks in the functional layers will be assessed according to the different studied scenarios. Finally, the impact of the mechanical damage on the electrochemical performances will be discussed. For that, electrochemical models already available at the laboratory will be used to quantify the precise effect of the mechanical damage on the system efficiency. The results will be compared to dedicated experiments for final validation. This work should allow providing guidance in terms of electrode microstructure design or on the heating and cooling protocol to avoid the degradation.

Dates: From autumn 2018 to autumn 2021 (3 years)

Host laboratory and collaborations: CEA-Grenoble/LITEN/DTBH/LPH. The mechanical tests will be performed at INSA-Lyon/MATEIS (Lyon) and the modelling analyses will be done in collaboration with EPFL/SCI-STI-JVH (Lausanne).

Applicant's profile: a specialization in mechanics and/or physics of materials will be appreciated.

Contacts: Joining CV, study marks and recommendation letter:
Jérôme Laurencin (CEA): Jerome.laurencin@cea.fr ; Sylvain Meille (INSA): sylvain.meille@insa-lyon.fr ; Arata Nakajo (EPFL): arata.nakajo@epfl.ch ; Jan Van herle (EPFL): jan.vanherle@epfl.ch

A master internship is proposed in preparation to the thesis (March-July 2028).